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# Influence of forest cover changes on regional weather conditions: estimations using the mesoscale model COSMO

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**Abstract.** This modeling study intends to estimate the possible influence of forest cover change on regional weather conditions using the non-hydrostatic model COSMO. The central part of the East European Plain was selected as the ‘model region’ for the study. The results of numerical experiments conducted for the warm period of 2010 for the modeling domain covering almost the whole East European Plain showed that deforestation and afforestation processes within the selected model region of the area about 105 km<sup>2</sup> can lead to significant changes in regional weather conditions. The deforestation processes have resulted in an increase of the air temperature and a reduction in the amount of precipitation. The afforestation processes can produce the opposite effects, as manifested in decreased air temperature and increased precipitation. Whereas a change of the air temperature is observed mainly inside of the model region, the changes of the precipitation are evident within the entire East European Plain, even in regions situated far away from the external boundaries of the model region.

## 1. Introduction

Comprehensive studies of forest – atmosphere interaction at different spatial and temporary scales (from ecosystem to regional and global scales) are important challenges in modern meteorology and ecology nowadays. To examine these scientific problems a wide range of experimental and modeling studies was being provided during the past several decades [1-8]. The main attention in those studies was mainly focused on assessing the response of forest ecosystems to the change of environmental conditions and on determining the influence of deforestation and land-use changes on regional and global weather and climatic conditions in past epochs, under present climate and under different scenarios of projected future climate changes [5, 6, 9-12]. The numerous results obtained, however, do not yet allow a complete assessment of all available relationships and effects arising between atmospheric processes and the land surface. A high degree of uncertainty still remains in the description of vegetation and atmosphere interaction at the regional scale. Reliability of the regional and global models that are usually used in such studies is limited by multiple model simplifications and deficiency of necessary input parameters describing the variety of the processes influencing the vegetation - atmosphere interaction. Furthermore, the accuracy of these simulations is also limited by significant heterogeneity of vegetation cover and surface topography. In this regard, it will be useful to



develop and apply more physically reasonable and sophisticated modeling approaches describing the land surface and vegetation properties, vegetation response to the change of ambient conditions and its interaction with the atmosphere. Within the frameworks of the study, numerical experiments using the mesoscale model COSMO to assess the possible influence of forest cover change in the central part of the East European Plain on regional weather conditions have been conducted. The main objective of the study is to quantify the possible effects of forest cover changes on spatial temperature and precipitation patterns within the East European Plain.

## 2. Material and methods

Within the frameworks of the modeling study to assess the influence of deforestation and afforestation processes on regional weather conditions, a series of numerical experiments using the non-hydrostatic limited-area atmospheric projection model COSMO were instigated [13, 14]. The TERRA model is used within COSMO to describe the land surface-atmosphere interaction [15]. To describe the energy and water transfer at the land surface - atmosphere interface, the model describes: the turbulent exchange within the atmospheric surface layer, stomatal regulation of plant transpiration, and root water uptake from different soil horizons (down to 23 m depth). The parameters characterizing the properties of soil and vegetation are taken from external global land cover data bases (GLC2000 and GLCC) at 30" of arc (about 1 km) resolution and from the digital soil map of the world (DSMW). The results of recent model validation provided using regular meteorological observations from about 150 weather stations located in European part of Russia showed a high quality of COSMO system projections for various parameters and under broad range of weather conditions [14].

The 'model region' selected for the study is situated in the central part of a large modeling domain which covered almost the entire East European Plain and is bounded by geographical coordinates 55° and 59°N and 28° and 37°E. Thus, the area of the model region is about 10<sup>5</sup> km<sup>2</sup>. The forests cover about 50% of the area and consist mainly of coniferous tree species in the north and broad-leaved species – in the south. Within the model region the different scenarios of forest cover change were simulated. The modeling study included three main numerical experiments. The first modeling experiment assumed the total deforestation of the model region and replacement of the forest communities by grasslands. The second experiment was a scenario of total afforestation of the model region. It assumed the suspension of logging and active forest regeneration and growth in agricultural and abandoned lands. It also supposes that an increase of forest cover in the scenario is mainly due to pioneer small-leaved tree species (e.g. birch, aspen). In the third 'control' experiment the weather conditions were simulated under the present land-use and vegetation structure of the model region.

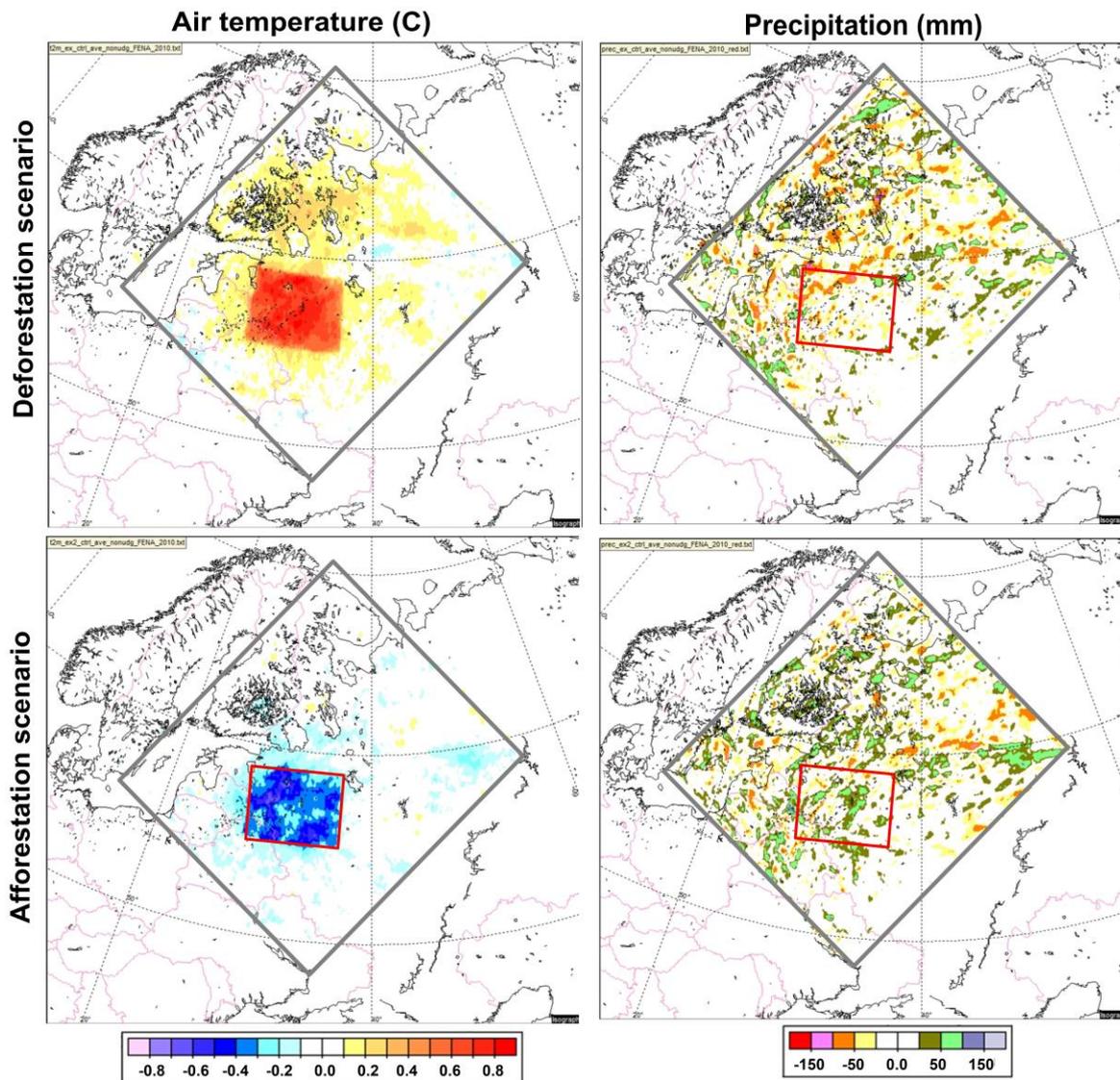
The numerical experiments to assess the effect of forest cover changes on regional weather conditions were conducted for a modeling domain located between 50° - 70° N and 15° - 55° E, and covering almost the entire area of the East European plain. The output of the numerical experiments was provided at a 13.2 km grid resolution. The ERA-Interim global atmospheric reanalysis (with 6-hour resolution in time and 0.75°×0.75° – in space) was used to quantify the initial and boundary conditions [16].

For our modeling experiments, the warm period of 2010 (from May to September) was used. It was characterized by various and very contrasting weather conditions. A unique feature of the selected period was extremely hot and dry weather in the middle of summer (July - beginning of August). Such various weather conditions allows us to reflect more clearly on the possible regulating mechanisms of forest vegetation of the energy and water exchange processes under different temperature and soil moisture conditions.

## 3. Results and discussion

The results of numerical experiments describing the effects of total deforestation and afforestation of the model region on regional weather conditions showed that the modern forest cover and land-use changes can significantly influence the atmospheric parameters, not only within the selected model region, but also in the areas situated within the modeling domain far away from the actual model

region (figure 1, tables 1-2). The spatial patterns of the temperature and precipitation changes under deforestation and afforestation scenarios show their very strong spatial heterogeneity. Whereas the significant changes of the air temperature can be seen in internal areas of the model region only, the changes of precipitation amount can be traced within the entire modeling domain (figure 1).



**Figure 1.** Simulated differences in the air temperature ( $^{\circ}\text{C}$ ) and precipitation rate (mm) for the selected modeling domain between the deforestation and afforestation scenarios of the model region and the control experiment, assuming present land-use structure for the entire modeling period from May to September 2010. The red square indicates the boundaries of the model region and the grey square shows the boundaries of the selected modeling domain.

**Table 1.** Simulated air temperatures, T (°C) for the selected model region and entire modeling domain and the temperature differences  $\Delta T$  (°C) between deforestation and afforestation scenarios in the model region and the control experiment assuming present land-use structure for the modeling period from May to September 2010.

Numerical experiments		Months					Mean
		5	6	7	8	9	
Model region							
Present land-use	T	9.6	11.9	19.0	15.5	9.2	13.0
Deforestation scenario	T	9.7	12.1	19.6	15.7	9.2	13.3
	$\Delta T$	+0.1	+0.2	+0.6	+0.2	0.0	+0.3
Afforestation scenario	T	9.5	11.8	18.8	15.4	9.1	12.9
	$\Delta T$	-0.1	-0.1	-0.2	-0.1	-0.1	-0.1
Entire model domain							
Present land-use	T	11.8	14.7	20.9	18.3	10.9	15.3
Deforestation scenario	T	11.9	14.7	21.1	18.4	10.9	15.4
	$\Delta T$	+0.1	0.0	+0.2	+0.1	0.0	+0.1
Afforestation scenario	T	11.8	14.7	20.9	18.3	10.9	15.3
	$\Delta T$	0.0	0.0	0.0	0.0	0.0	0.0

**Table 2.** Simulated precipitation amount, P (mm), for the selected model region and entire modeling domain and the precipitation differences  $\Delta P$  (%) between the deforestation and afforestation scenarios in the model region and the control experiment assuming present land-use structure for modeling period from May to September 2010.

Numerical Experiments		Months					Mean
		5	6	7	8	9	
Model region							
Present land-use	P	75.2	79.4	47.4	52.1	68.4	322.5
Deforestation scenario	P	74.9	77.5	43.6	47.5	67.9	311.4
	$\Delta P$	-0.4	-2.4	-8.0	-8.8	-0.7	-3.4
Afforestation scenario	P	75.6	83.1	49.5	53.4	69.7	331.3
	$\Delta P$	+0.5	+4.8	+4.8	+2.7	+1.9	+2.8
Entire model domain							
Present land-use	P	50.5	57.8	37.4	49.0	57.6	252.3
Deforestation scenario	P	51.0	56.1	35.9	47.3	57.5	247.8
	$\Delta P$	+1.0	-2.9	-4.0	-3.5	-0.2	-1.8
Afforestation scenario	P	50.6	58.3	37.8	48.9	57.8	253.4
	$\Delta P$	+0.2	+0.9	+1.1	-0.2	+0.3	+0.4

Under the scenario imitating deforestation processes the mean air temperature within the model region was higher than that was obtained in the control experiment. Under the afforestation scenario the mean air temperature, on the contrary, was lower than under the control conditions (tables 1-2). The maximum temperature differences between both scenarios imitating the forest cover changes and the control experiment were obtained for the summer months (July):  $+0.6\text{ }^{\circ}\text{C}$  – for the deforestation scenario and  $-0.1\text{ }^{\circ}\text{C}$  – for the scenario with afforestation, respectively. For the areas situated within the modeling domain but outside of the control region the changes in air temperature are manifested quite poorly due to forest cover change (figure 1). Under the deforestation scenario the temperature difference with respect to the control experiment gradually decreases with an increase of the distance from the external borders of the model region. Any meaningful influence of afforestation of the model region on the average temperature of the entire modeling domain is not revealed. The results of numerical experiments are also showed that under the anomalous weather conditions of 2010 the total deforestation in addition to projected temperature growth also leads to an increase in duration of the periods with abnormally hot weather (the periods with average daily air temperature exceeding the mean climatic values by at least  $7\text{ }^{\circ}\text{C}$ ). At the same time, for the scenario imitating total afforestation of the model region the duration of the periods with anomalously hot weather, on the contrary, slightly decreased.

Analysis of diurnal variability of the air temperature shows that the maximum differences between the forest cover change scenarios and the control experiment is predicted for daylight hours. Calculations show that for the period of anomalously hot weather in the summer of 2010 the daytime temperatures obtained for the model scenario imitating the total deforestation of the model region could exceed the temperatures of control experiment at modern land-use and forest structure by  $2\text{-}6\text{ }^{\circ}\text{C}$ . Under the scenario imitating total afforestation the daytime temperatures were slightly lower than the values under the control experiment (by  $2\text{-}5\text{ }^{\circ}\text{C}$ ).

The influence of forest cover change within the model region on precipitation is manifested in an increase of its total amount under the afforestation scenario, and in its decrease under the scenario imitating total deforestation (tables 1-2). The maximum increase of precipitation ( $+4.8\%$ ) for the model region under the afforestation scenario was predicted for June-July, and its maximum decrease ( $-8.8\%$ ) under deforestation scenario for July - August, i.e. in the hottest months of 2010. As already mentioned, the influence of forest cover changes on spatial precipitation pattern is clearly extended beyond the model region to the entire modeling domain of the East European Plain (figure 1). In particular the decrease of precipitation in July for the entire modeling domain under the scenario imitating deforestation processes in relation to precipitation under the control experiment was about  $4\%$ . Thus, despite the rather small (about  $10\%$  in relation to the size of modeling domain) area of the model region, the modeling experiments show a notable influence of forest cover changes on precipitation pattern within the entire modeling domain of the East European Plain. For the scenario imitating afforestation processes, the total amount of precipitation in July exceeded its amount in the control experiment by  $5\%$  for the model region and by about  $1\%$  for the entire modeling domain, which also gives evidence for the essential redistribution of precipitation outside the boundaries of the model region.

During the last decades in numerous experimental and modeling studies considerable attention was given to the effects of forest and land-use changes on local and regional meteorological conditions [6, 8, 17 - 19]. Most of the studies show an excess of day and daily mean values of the air temperature in deforested areas over its values in undisturbed forest stands. These results are therefore well in agreement with the estimations obtained in our numerical experiments. The influence of the forest and forest cover change on precipitation is still under-investigated.

The main mechanisms that are responsible for the influence of deforestation processes on weather conditions are: change of surface albedo and surface roughness, decrease of evaporative water loss into the atmosphere in deforested sites, and their additional heating that can lead to the strengthening of local convective instability in the lower troposphere. It is obvious that the influence of all these factors in different seasons, under various synoptic situations and for different land surface types can

result in effects that can be quite difficult to predict. The influence of afforestation is manifested in a general increase of water vapor intake into the atmosphere due to the higher transpiration rate of forest vegetation in comparison with evaporation from bare soil or transpiration of grassy vegetation. The water vapor released into the troposphere can be both condensed and immediately returned to the earth as convection rainfall (that occurs quite seldom) or (most often) returned as rain after some delay following its translocation, depending on the current atmospheric conditions.

To parameterize the surface evapotranspiration the COSMO model takes into account aggregated information about land-use structure, forest cover and species composition, surface roughness and albedo, leaf area index (LAI), root depth, and biophysical properties of vegetation cover (e.g. stomatal conductance). Several recent modeling studies [4, 6] showed that, in the case of deforestation of boreal forests, the higher albedo during the winter and spring period can play a key role in regulation of land surface temperature. Higher contribution of snow cover to the albedo of the land surface in deforested areas in comparison with undisturbed forest sites during the winter period and in the early spring can lead to decrease in short-wave radiation balance of ground surface and, as a result, to air temperature reduction. The effects of afforestation can result in the opposite effects. Taking into account a strong influence of surface albedo on temperature regime of land surface, it is also very important to consider a very strong impact of the biophysical properties of vegetation on net radiation and sensible and latent heat fluxes between land surface and the atmosphere. Large differences in the biophysical properties of forest and grassy vegetation have not been completely taken into account in global and regional mathematical models yet. It can obviously result in some uncertainties in model predictions.

#### 4. Conclusion

The results of numerical experiments provided using the COSMO model for warm period of 2010, taken as an example, have shown that deforestation and afforestation processes can result in significant changes of weather conditions in the area of the East European Plain. Numerical experiments indicate the existence of a complex system of relationships between forest vegetation and the atmosphere.

It is obvious that available numerical models are able to predict the possible response of regional weather conditions to changes of land surface and vegetation properties only within the model parameterizations and approximations used for describing the real atmospheric and land surface processes. That requires involving more sophisticated modeling approaches that are allowed to describe the forest - atmosphere interaction in detail and that are validated against experimental data. The numerical experiments provided should be considered as a part of a multidisciplinary study of possible effects of forest cover changes on regional and global weather conditions.

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